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Faculty of Forest Sciences

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Skattning av maximala tätheter av ensamrig öring, *Salmo trutta*, med hjälp av omvärldsdata

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Examensarbete i ämnet biologi

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Abstract

Brown trout, *Salmo trutta*, is an important species for the sportfishing tourism in Sweden and goals are set high for the possible gains to come from fishing tourism. Therefore accurate and efficient methods to estimate a streams potential production of brown trout are needed in order to apply relevant management regimes that take fish ecology into account and prevents overfishing. One measure of brown trout production is the density of young of the year fish. The usual method for estimation of young of the year brown trout density are electrofishing with three removals. In this study a method using environmental factors to estimate maximum production of young of the year brown trout, as a measure of carrying capacity, was used. Based on previous studies environmental factors important for brown trout habitat requirement were selected. Data of stream slope, water flow, annual air temperature, longest period above 0 °C, altitude, stream width and water depth were linked to data on young of the year densities in a cluster analysis. The percentage relative precision values for the estimated mean maximum densities showed a lower level of uncertainty for density estimates based on environmental factors and cluster analysis than for estimates based on electrofishing with three removals. An additional benefit of the use of environmental data for estimations of maximum young of the year brown trout density is that estimates can easier be scaled up to cover a whole stream without the use of long time series of data. As opposed to estimation of brown trout production capacity for a whole stream using electrofishing data which for reliable estimates require over time data (e.g. 10-15 years).

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1. Introduction

Brown trout, *Salmo trutta*, is one of the most important fish species for leisure and sport fishing in Sweden today, both concerning freshwater fishing (streams and lakes) and coastal fishing. Each year approximately 1.6 million Swedes and 800 000 foreign tourists exercise some form of leisure or sport fishing in Sweden and they have an estimated yearly expenditure of 5.8 billion sek (HaV, 2014; Tillväxtverket, 2016). In 2013 the retained catch of brown trout for freshwater fishing in lakes and streams was estimated to around 1 340 000 kg and for coastal and marine fishing to around 910 000 kg (HaV, 2014). The Swedish Agricultural ministry has together with the Swedish Agency for Marine and Water Management developed a vision for the future of the fishing tourism in Sweden. Their vision state that “in 2020 the fishing tourism should be at least doubled, an important part of the tourism industry, generate work opportunities, and substantial socioeconomic values” (Jordbruksverket & HaV, 2013). At the same time brown trout is one of the fish species in Sweden for which local population sizes and production have experienced serious declines during the last century, mainly due to different types of habitat degradation both in fresh water and in the Baltic sea, and due to overexploitation (ICES, 2011a; ICES, 2011b). According to ICES (2015) the Baltic sea trout populations are in a lower than optimal state and the brown trout exploitation rates should be reduced in the Baltic sea area. To restore the brown trout production in streams much faith and resources are directed into river restoration projects but there is a gap between the actual production of brown trout in Swedish streams and the production of brown trout that is expected from the fishing tourism industry. A way to generate estimates with low uncertainties of brown trout production for a stream in a cost effective way and a way to indentify streams with high brown trout production potential are needed to meet the demands from the fishing tourism industry. The usual way to estimate the brown trout production in a stream is to use data of young of the year brown trout density that are collected in electrofishing monitoring programs. Establishing reliable maximum production estimates are time and cost consuming since data collection has to be done several years to create time series. A less time and cost consuming way to estimate the production of brown trout in a stream is to use environmental factors that have a documented effect on brown trout production. Models that use environmental data to estimate brown trout production or population size have been experimentally used and have been found to be able to give estimates with low uncertainty levels (Lobón-Cervía & Rincón, 2004). Although these type of models will give a simplified picture of the reality (as will all kinds of census techniques) they can still be useful to estimate production or population size or to identify streams with good brown trout habitat (Milner et al., 1998). Rahel & Nibbelink (1999) concluded that data of environmental factors could successfully be used to identify streams that contain brown trout populations and to choose how to direct restoration efforts in streams that have lower brown trout production than they could have. For a model to give accurate enough estimates it should contain both environmental data directly connected to stream structure, such as factors connected to stream size, and also data covering more general environmental factors, such as temperature and altitude (Heggenes, 1996).

There are a number of environmental factors affecting and restricting the available habitat of brown trout and therefore also affecting the production of brown trout in a stream. Most of these environmental factors are correlated in one way or another making it difficult to distinguish which environmental factors that are most important for brown trout production (Milner et al., 1998). Environmental factors that have been described in the scientific literature as important for the production of brown trout are water depth, stream width,

water flow, air temperature, length of the growing season, stream slope and altitude (Armstrong et al., 2003; Gatz et al., 1987; Daufresne et al., 2005; Rahel & Nibbelink, 1999; Bret et al., 2016; Eklöv et al., 1999; Parra et al., 2014). One of the most important environmental factors for brown trout production is stream size and it is the water depth, stream width and water flow that are commonly included in the term stream size (Eklöv et al., 1999). Both water depth and stream width have been shown to be negative correlated to young of the year brown trout density (Bohlin et al., 2001). Water depth is an important environmental factor as young brown trout seek night time refuge in shallow areas where they have less risk of being preyed upon (Bardonnnet et al., 2006). In contrast to young brown trout the abundance of larger brown trout is limited by the availability of deeper stream sections, especially in smaller streams (Heggenes, 1996). One reason to the negative correlation between young of the year brown trout density and stream width might be that the preferred habitat of young of the year trout to a large extent is the stream edges as opposed to in-stream habitat. Therefore smaller streams have a bigger proportion habitat suitable for young of the year brown trout compared to larger streams (Eklöv et al., 1999). Vøllestad et al. (2002) looked at small streams in Norway and found evidence of density dependence for brown trout and stream size (e.g. stream width) to be positively correlated to growth rate at the individual level for all age classes. Water flow is considered an important factor for brown trout production as changes in flow conditions affect young of the year brown trout behavior. At low water flows young of the year brown trout move less and use coarser substratum (Riley et al., 2009). High water flow has been found to influence brown trout negatively during emergence and in early life stages. High flow conditions can destroy gravel beds and brown trout also have a low resilience if often exposed to high water flows (Crisp, 1996; Bret et al., 2016). Higher water flow can also be positive for brown trout survival as it works like a buffer, in the summer keeping the water temperature down and in the winter keeping the water temperature from sinking to low (Hari et al., 2006). Water flow is also, in combination with temperature, one of the environment factors that trigger brown trout migration. Both smolt sea migration and homing of adult trout are thought to be initiated by water flow fluctuations (Hembre et al., 2001; Crisp, 1996). There are different opinions of the effect of the stream slope on brown trout production. Safe to say is that the habitat structure of a stream differs with high and low stream slope and that stream slope in that way affects the conditions for brown trout production. Chisholm & Hubert (1986) found that a high stream slope had negative impact on brown trout abundance. Kozel et al. (1989) found that a higher abundance of trout in streams with low stream slope could be connected to more pool habitat and cover in streams with lower stream slope compared to streams with higher stream slope. Isaak & Hubert (2000) argued that the stream slope may affect brown trout populations depending on scale, at the stream scale they found no negative effect of higher stream slope on trout populations, but for a stream reach the stream slope affected both the brown trout density and their length structure. The air temperature is considered an important environmental factor for brown trout production as air temperature determine physiological processes, the geographical distribution, the water temperature and the growing season of a cold water fish like brown trout (Eaton et al., 1995; Rahel et al., 1996; Rahel & Nibbelink, 1999). Another environmental factor important for brown trout is altitude. For migratory brown trout altitude has a negative effect on recruitment and the young of the year density declines with higher altitude (Bohlin et al., 2001). Migratory female brown trout at higher altitudes mature later in life and at a larger body size than females at lower altitudes. With this they compensate their fitness with a higher fecundity at old age, despite a longer life (Parra et al., 2014).

The objective with this master thesis was to investigate if it is possible to use environmental data that are known to affect the production of brown trout to estimate a rivers total maximum production capacity of brown trout expressed as the density (0+/100m²) of young of the year brown trout. A main question was if the use of environmental data to estimate brown trout production for a stream would be reliable and a more time and cost effective way than to use traditional electrofishing. I used environmental factors that have been documented to influence the production of brown trout in streams to find out which environmental factors that are most important for brown trout production. With my thesis I want to contribute to the understanding of which environmental parameters that affect brown trout production the most and how these can be used to estimate maximum production capacity of young of the year brown trout.

2. Material and methods

Data covering environmental factors that have been documented to influence the production of brown trout in streams were matched with electrofishing data of density of young of the year (0+) brown trout. Thereafter cluster analyses and ANOVA tests were made to investigate if the young of the year brown trout production could be estimated using suitable environmental factors as opposed to traditional electrofishing. PRP (percentage relative precision) calculations of the relative uncertainty of the mean 0+ densities were made to see how the levels of uncertainty would spread for estimated 0+ brown trout densities based on a streams summed up 0+ brown trout production compared to estimated 0+ brown trout densities based on electrofishing of a whole stream.

Selection of which environmental factors to use was done based on information about habitat suitability for brown trout in the scientific literature (ICES, 2011c; Armstrong et al., 2003; Eklöv et al., 1999). The environmental factors that were chosen for the analyses were water depth, stream width, water flow, stream slope, altitude, mean annual air temperature and longest period above 0 °C. The air temperature and water flow data were downloaded from websites by SMHI, Sweden's Meteorological and Hydrological Institute. The electrofishing data density of 0+ brown trout, water depth, stream width and altitude for each electrofishing site were downloaded from SERS, the Swedish Electrofishing Register. The slope of the stream for each electrofishing site was calculated with the use of a GIS DEM (digital elevation model).

2.1 Electrofishing data

Data covering all electrofishing sites in Sweden that had been fished for 10 years or more before the year of 2016 was downloaded from <http://www.slu.se/elfiskeregistret> (SERS, 2016). For each electrofishing site the data of the three years with the highest densities of young of the year (0+/100 m²) brown trout were selected to be used in the analyses. In addition to 0+ densities the SERS data contained information of air and water temperature at the fishing occasion, water depth, stream width, altitude, type of nearby environment, size of the fished area, number of species and distance to the closest downstream and upstream lake for each electrofishing site. Regression analysis where the 0+ densities were compared to each of the additional environmental factors in the SERS data was used to decide which of the environmental factors in the SERS data that affected the 0+ density most and therefore should be selected to be used in the statistical analyses. The environmental factors from the SERS data selected for the statistical analyses were:

- Mean water depth (m)
- Mean stream width (m)
- Altitude (m.a.s.l.)

2.2 Flow and temperature data

Data of the water flow in the outflow of each of Sweden's drainage areas during the period 1981-2010 as well as data of land use, soil type and phosphorous and nitrogen load for Sweden's drainage areas were downloaded from SMHI's "Vattenwebb" (SMHI, 2016a). The water flow data used in the analyses were the annual averages representative for each electrofishing site. Each water discharge data had an ID number connected to a specific drainage area. These drainage areas were downloaded as a GIS polygon data layer from SVAR, the Swedish Water Archive, a database operated by SMHI (SMHI, 2016b). Data of mean annual air temperature as measured by Sweden's weather stations were downloaded from SMHI. Each electrofishing site was connected to the temperature data of its closest weather station. Using the temperature data the median longest continuous period above 0 °C for each electrofishing site was calculated. Regression analysis where the 0+ brown trout densities were compared to each of the environmental factors in the SMHI data was used to decide which of the environmental factors from the SMHI data that affected the 0+ density most and therefore should be selected to be used in the statistical analyses. The environmental factors from the SMHI data selected for the statistical analyses were:

- Annual mean water flow (m³/s)
- Mean annual air temperature (°C)
- Longest period above 0 °C (days)

2.3 Compilation of the data in GIS

Using the coordinates for each electrofishing site a GIS point data layer was created, showing a point for each electrofishing site. The data points were adjusted so that all of the electrofishing sites actually were located within their stream. This was done using a DEM with a resolution of 2x2 meters (Figure 1A). When it was hard to distinguish a stream only by the use of the DEM layer an orthophoto layer was used for visualization (Figure 1B). The water flow data were connected to the attribute table of the drainage area polygon data layer. Thereafter the attribute data of the drainage area polygon layer were connected to the electrofishing sites point layer using a spatial join tool. Each electrofishing site point got the water flow data of the drainage area of which the point was geographically placed.

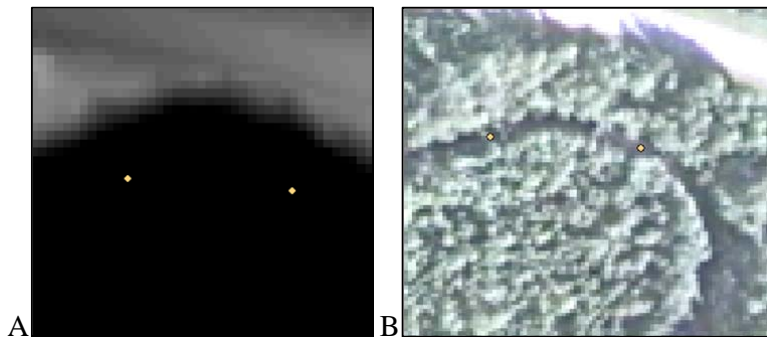


Figure 1. Two electrofishing site points, A: DEM layer background, B: orthophoto layer background.

2.4 Calculation of the stream slope

Calculation of the stream slope for each electrofishing site was done using elevation data extracted from a DEM (digital elevation model) layer with a resolution of 2x2m from the Swedish National Land Survey. The DEM layer provided by the Swedish National Land Survey was made using 3D laser scanning and represents coherent elevation values of the topographic surface of Sweden (Lantmäteriet, 2015). The elevation data used in the calculation of stream slope for each electrofishing site was extracted from the center of each stream, where the uncertainty of the elevation data should be at its smallest. It was decided to calculate the stream slope using this method as the interpolation methods used to calculate the slopes from the DEM layer directly in GIS provides inaccurate estimates because of the rough interpolation method used so far by the Swedish National Land Survey for water surfaces.

A GIS data layer of circles around each of the electrofishing site points was created with the use of a buffer tool. The buffer circles got a radius of 100 or 200 meters around the electrofishing site points depending on stream size (Figure 2A and B). For each electrofishing site five points in a row following the stream were created in an empty GIS point data layer. The points were put approximately 50 or 100 meters apart depending on the size of the stream. The first point was placed upstream the electrofishing site point where the stream and the buffer circle intersect and the last point was placed where the stream and the buffer circle intersect downstream of the electrofishing site point. The middle (third point) was placed at the electrofishing site point. The remaining two points were placed between the first and the third point and between the second and the third point (Figure 2C).

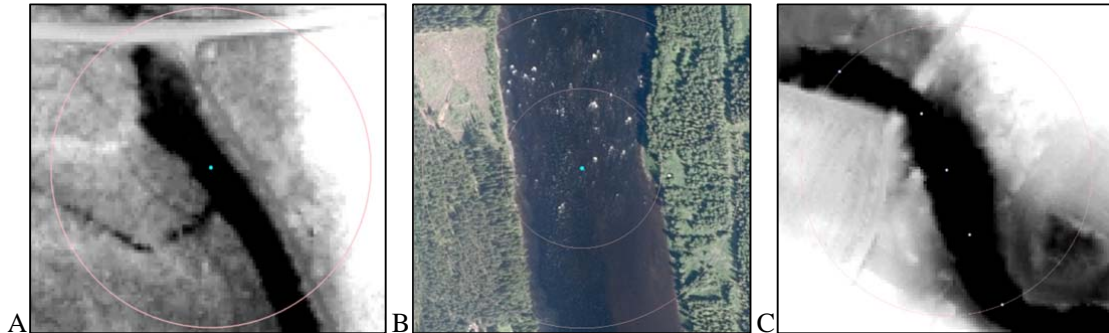


Figure 2. Three different electrofishing sites in streams of different size. A: Electrofishing site with 100 meter radius buffer circle, DEM layer background, B: electrofishing site with 100 and 200 meter radius buffer circles, orthophoto layer background. C: Electrofishing site with five GIS data points and 100 meter buffer circle. Electrofishing site point in the middle, DEM layer background.

Elevation data from the DEM layer was extracted to each point and the slopes were then calculated between nearby points (Equation 1). The average, maximum and minimum slope of each electrofishing site were calculated. Regression analysis where the 0+ brown trout densities were compared to each of the different slope categories was used to decide which of the three slope categories that affected the 0+ density most and therefore should be selected to be used in the statistical analyses. The maximum slope of each electrofishing site was used in the statistical analyses as this turned out to best explain the density of 0+ brown trout.

Equation 1. h is the height values (extracted from the DEM layer), x is x-coordinate and y is y-coordinate for the GIS data points.

$$\frac{h_1 - h_2}{\sqrt{((x_1 - x_2)^2 + (y_1 - y_2)^2)}}$$

2.5 Statistical analyses

The statistical analyses were performed using the software R (R Development Core Team, 2008). The data of the environmental factors water depth, stream width, water flow, stream slope, mean annual air temperature, longest period above 0 °C and altitude was standardized using the function *scale*. Using the function *PAM* (partitioning around medoids), a more robust version of the K-means algorithm (Reynolds et al., 1992), the dataset was divided into clusters. The algorithm used in the *PAM* function divides the dataset into a fixed number of clusters with the most alike data in the same cluster. Clusters are created around medoids (e.g. data inputs that are representative for the dataset structure) by the rest of the data values which are assigned to the medoid they are closest to. To find the optimum number of clusters solutions with 2 to 10 clusters were tested and the solution selected was the one with optimum average silhouette width using the method described by Kaufman & Rousseeuw (1990). The *PAM* algorithm is implemented in the R package *cluster* (Maechler et al., 2015) and the optimum silhouette width function in package *fpc* (Hennig, 2015). Mean values of 0+ brown trout densities and the mean values of the environmental factors for each cluster were calculated. ANOVA was used to test if the difference in mean values of 0+ brown trout densities and mean values of the environmental factors were significant between the clusters.

PRP (percentage relative precision) values for the mean values of 0+ brown trout densities were calculated for all clusters together and for each cluster apart. The PRP values were calculated as the mean difference between the 95% confidence limits and the mean densities of 0+ brown trout for all clusters together and for each cluster apart. The PRP values are a percentage of the mean densities and tell the relative uncertainty of the means (Sutherland et al., 2006). Using "the general case of k removals" as proposed by Bohlin et al. (1989) estimated densities of 0+ brown trout and catchability based on traditional electrofishing with 3, 4 and 5 removals was obtained (Equation 2 and 3). For the case with 3 removals cumulative catchabilities were used ($p_1 = 0.48$, $p_2 = 0.70$ and $p_3 = 0.90$) as calculated by Bergquist et al. (2014) based on approximately 10 000 three-pass electrofishing occasions from all of Sweden. After estimation of 0+ brown trout densities and catchabilities based on traditional electrofishing, calculations of PRP values for the estimated densities of 0+ brown trout with 3, 4 and 5 removals was made in the same way as for the clusters PRP values.

Equation 2. k is number of removals, T is total catch, p is catchability and q is $1 - p$ (Bohlin et al., 1989).

$$\frac{\hat{q}}{\hat{p}} - \frac{k\hat{q}^k}{1 - \hat{q}^k} = \frac{\sum_{i=1}^k (i-1)c_i}{T}$$

Equation 3. Estimation of population size (y) (Bohlin et al., 1989).

$$\hat{y} = \frac{T}{(1 - \hat{q}^k)}$$

3. Results

815 electrofishing sites (FS) had been fished for 10 years or more before 2016 and data from the three years with highest densities of 0+ brown trout from these 815 FS were selected to be used in the statistical analyses. This gave in total 2445 electrofishing occasions (FO) located all over Sweden except for Öland and Gotland (Figure 3A). For the 2445 FO the mean 0+ brown trout density was 55.44/100m² (LCL = 51.66 and UCL = 59.22). The 0+ densities data from the 2445 FO contained density values from 0.1 to 1850/100m² (Figure 3B). Circa 30% of the FO had low 0+ brown trout densities, between 0.1 - 10/100m², while most part (ca 55%) of the FO had slightly higher densities, between 10 - 100/m² and circa 15% of the FO had much higher densities than the rest of the FO, between 100 - 1850 (Table 1).

Table 1. Distribution of 0+ brown trout density among the 2445 fishing occasions.

Number of fishing occasions	Density (0+/100m ²)	Relative frequency (%)
67	0.1 - 1	3
641	> 1 - 10	26
992	> 10 - 50	41
352	> 50 - 100	14
343	> 100 - 300	14
50	> 300 - 1850	2

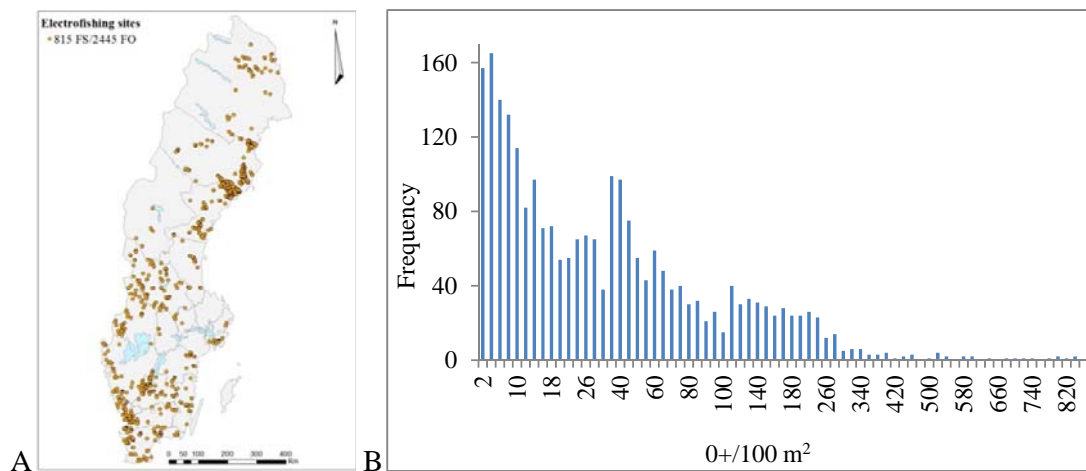
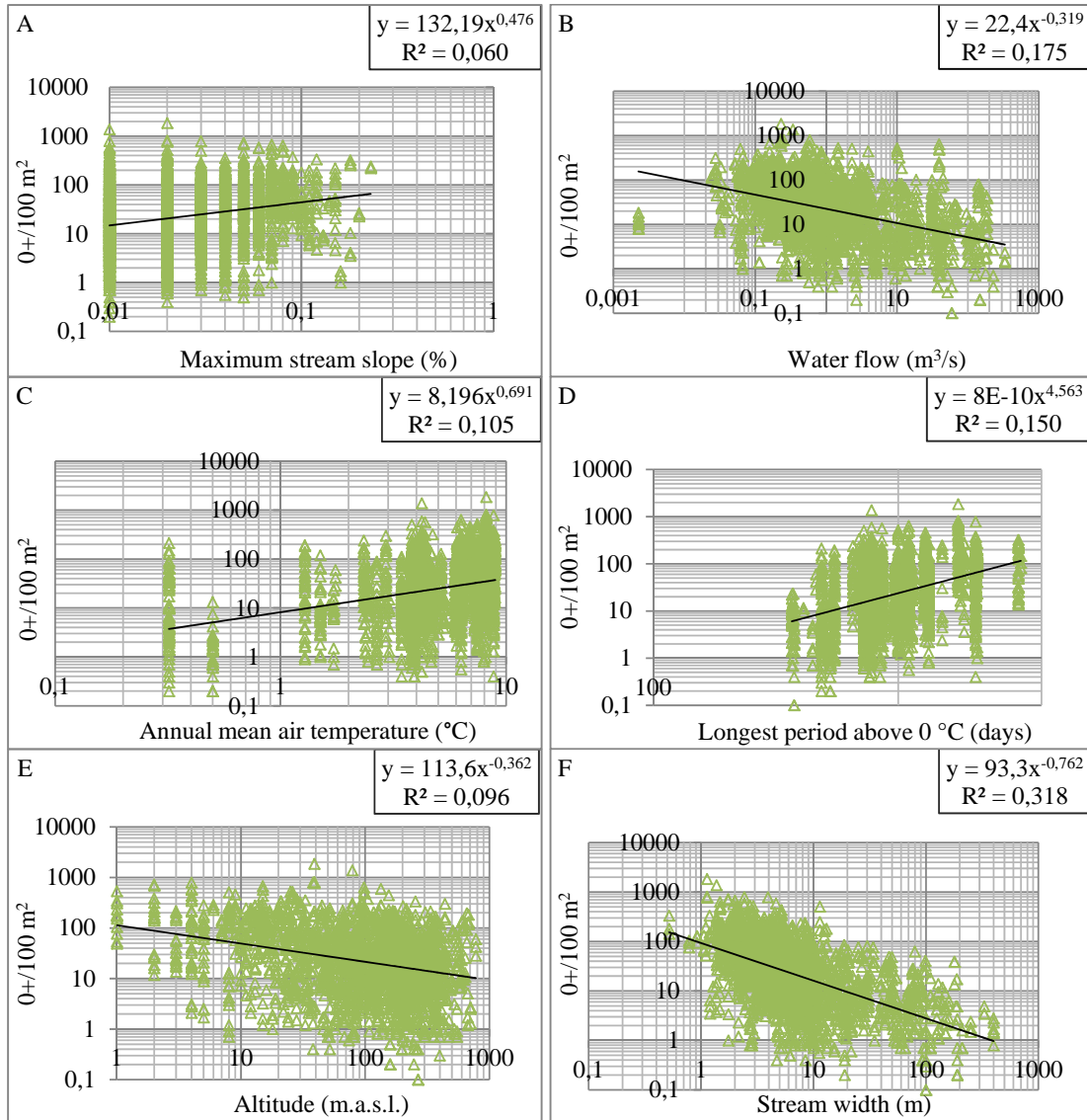


Figure 3. A: Geographical distribution of the 815 electrofishing sites used in the statistical analyses. B: Distribution of 0+ brown trout densities for the 2445 electrofishing occasions used in the statistical analyses.

3.1 Environmental factors

Based on regression analyses and suggestions from the scientific literature of which environmental factors that are the most important for brown trout habitat selection the environmental factors stream slope, water flow, annual mean air temperature, longest period above 0 °C, altitude, stream width and water depth were selected to be used in the statistical analyses. The R square values obtained in the regression analyses gave a hint of the connection between each of the environmental factors and the 0+ brown trout density. None of the regression analyses gave high R square values implying that the 0+ brown trout densities could not be explained using only one environmental factor at a time but rather with the use of several interconnected factors. Of the selected environmental factors stream

slope had the lowest R square value (6%), followed by altitude and annual air temperature (10%). The highest R square values were found for stream width (32%), water depth (20%), water flow (17%) and longest period above 0 °C (15%) (Figure 4A-G).



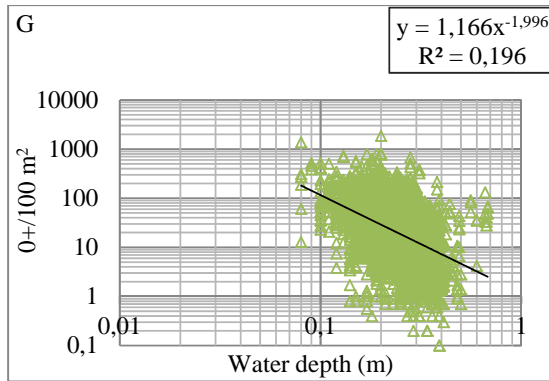


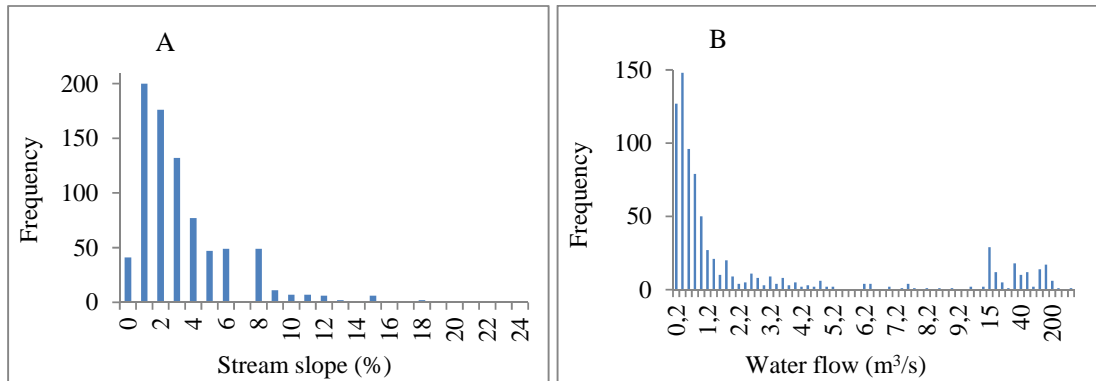
Figure 4. Connection between 0+ brown trout densities for the 2445 electrofishing occasions and each of the environmental factors selected for the statistical analyses. A: Maximum stream slope (%), B: Water flow (m³/s), C: Annual air temperature (°C), D: Longest period above 0 °C (days), E: Altitude (m.a.s.l.), F: Stream width (m) and G: Water depth (m).

The mean of the maximum stream slope values, one out of 4 measurements for each site, for the 815 FS was 3.28% (LCL = 3.16 and UCL = 3.39). The stream slope values ranged between 0 – 24% and a majority of the FS had stream slope values in the range 1 – 4% (Table 2 and Figure 5A). The annual mean water flow for the 815 FS ranged between 0.2 – 350m³/s, with a mean of 9.51m³/s (LCL = 8.35 and UCL = 10.68). The majority of the FS had a water flow between 0.2 - 1m³/s and a few FS had high to very high water flow values (Table 2 and Figure 5B). The mean annual air temperature for the 815 FS was 5.09 °C (LCL = 5.00 and UCL = 5.19) and the temperature values ranged between -1 and +9 °C (Table 2 and Figure 5C). The mean longest period above 0 °C for the 815 FS was 198.23 days (LCL = 197.23 and UCL = 199.24) and longest period above 0 °C values ranged between 146 – 286 days (Table 2 and Figure 5D). The mean altitude for the 815 FS was 157.04 m.a.s.l. (LCL = 151.72 and UCL = 162.36). There were a wide range of altitude values for the FS, from 1 – 800 m.a.s.l. (Table 2 and Figure 5E). The mean stream width for the 815 FS was 15.73 m (LCL = 14.30 and UCL = 17.16). There was a wide range of stream width values for the FS, from 0.5 – 410m (Table 2 and Figure 5F). The highest stream width values belonged to electrofishing sites in Sweden's largest rivers including the rivers Torne, Lainio, Kalix, Vindel, Muonio, Piteå and Ängesån. The mean water depth for the 815 FS was 0.24 m (LCL = 0.24 and UCL = 0.24). The water depth values ranged from 0.1 - 0.7m (Table 2 and Figure 5G).

Table 2. Distribution of environmental factor values for the 815 electrofishing sites.

	Interval	Number of sites	Relative frequency (%)
Stream slope (%)	0	41	5
	> 0 - 2	376	46
	> 2 - 4	209	26
	> 4 - 10	163	20
	> 10 - 24	26	3
Water flow (m³/s)	0.2 - 1	500	61
	> 1 - 2	87	11
	> 2 - 10	100	12
	> 10 - 50	89	11
	> 50 - 350	39	5

Annual air temperature (°C)	-1 - +3	129	16
	> +3 - +6	335	41
	> +6 - +9	351	43
Longest period above 0 °C (days)	146 - 176	112	14
	> 176 - 206	467	57
	> 206 - 286	236	29
Altitude (m.a.s.l.)	1 - 50	218	27
	> 50 - 150	222	27
	> 150 - 250	214	26
	> 250 - 800	161	20
Stream width (m)	0.5 - 10	622	76
	> 10 - 50	128	16
	> 50 - 110	45	6
	> 110 - 410	20	2
Water depth (m)	0.1 - 0.15	98	12
	> 0.15 - 0.3	575	71
	> 0.3 - 0.45	129	16
	> 0.45 - 0.7	12	1



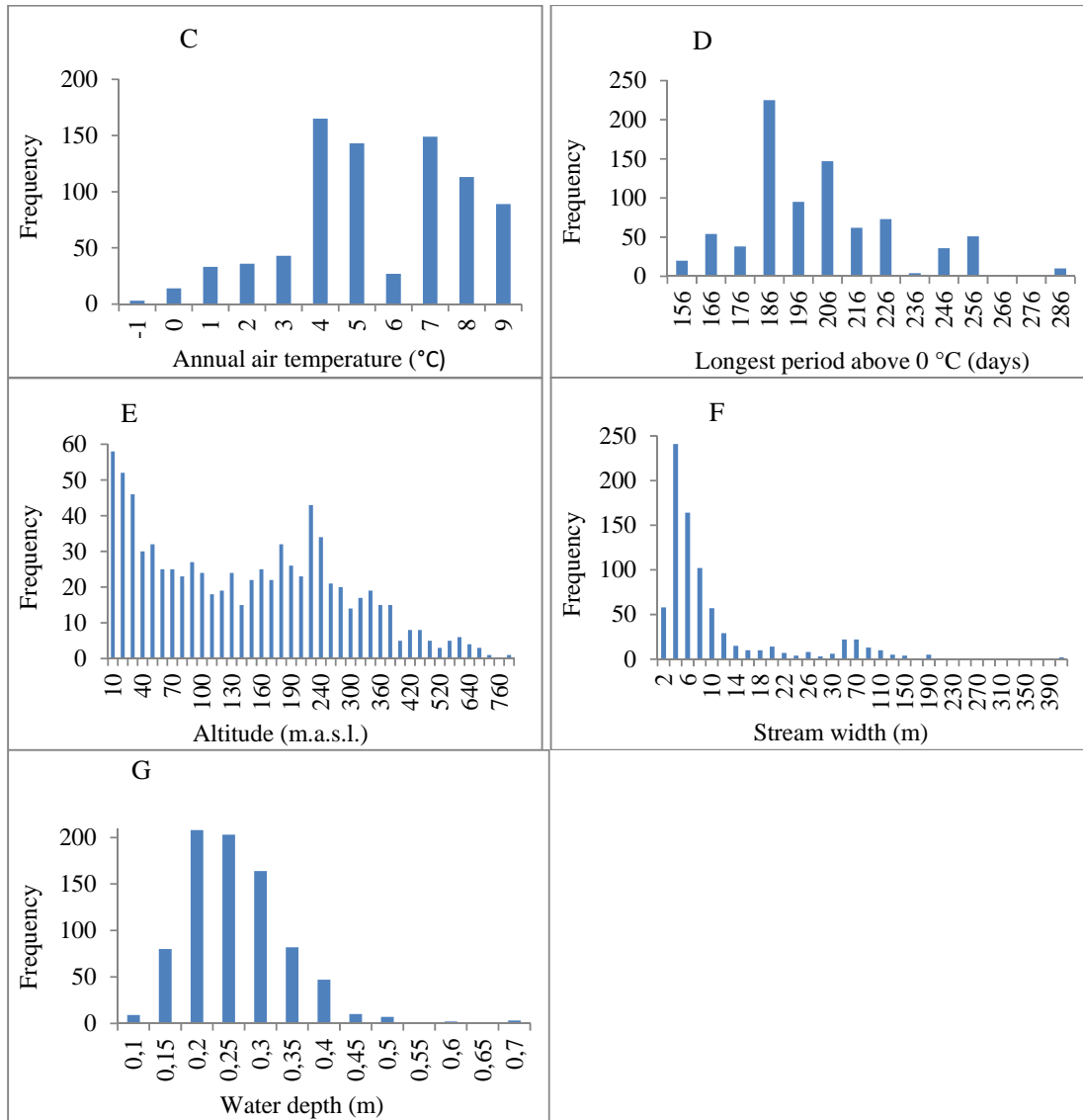


Figure 5. Distribution of A: Stream slope (%), B: Water flow (m^3/s), C: Annual air temperature ($^{\circ}\text{C}$), D: Longest period above 0°C (days), E: Altitude (m.a.s.l.), F: Stream width (m) and G: Water depth (m) for the 815 electrofishing sites that were used in the statistical analyses.

3.2 Cluster analysis

The cluster analysis was used to investigate if the electrofishing sites could be grouped by means of their similarity in the environmental variables. A grouping by environmental factors could then be useful to estimate production and its uncertainty of a brown trout population in relation to the environmental factors. According to the cluster analysis the optimal number of clusters for the data used was five. The five clusters contained 759, 906, 102, 396 and 282 electrofishing occasions each. Plotting of the clusters on a map showed some spatial differences between the clusters, both with clusters that could be tied to their own geographical regions and clusters that overlapped. The two clusters with the smallest geographical distribution were cluster 1 and cluster 3. Cluster 1 had the second most electrofishing occasions (759 FO) and was located in southern Sweden, mainly with electrofishing sites following the western and eastern coastlines from the county of Skåne up north to the county of Västra Götaland in the west and to the county of Stockholm in the

east. Cluster 3 had the least electrofishing occasions (102 FO) and was located in northern Sweden, mainly in the county of Norrbotten but also with a few electrofishing sites in the county of Västerbotten. Cluster 2 and cluster 4 overlapped (906 FO and 396 FO each), stretching from the lakes Vänern and Vättern in the south up north over the county of Värmland, following the east coast along the Gulf of the Bothnian Sea up north to the county of Västerbotten. Cluster 5 (282 FO) overlapped with cluster 3 in the counties Norrbotten and Västerbotten but had a larger geographic distribution than cluster 3 following the inland south to the county of Dalarna (Figure 6).

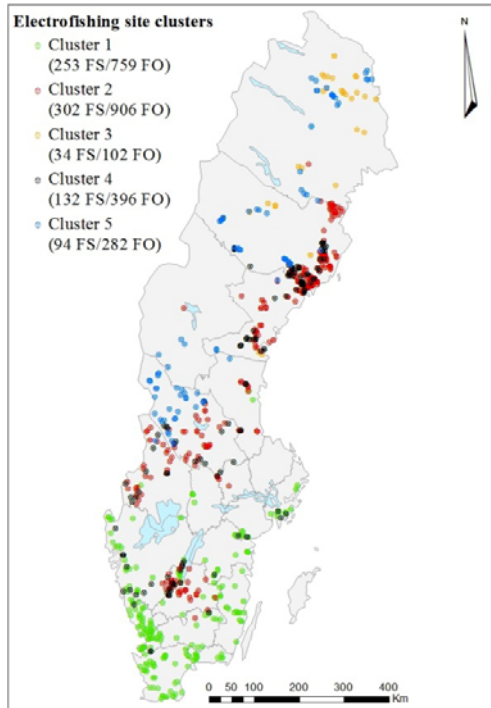


Figure 6. Geographical distribution of the five clusters, each of the five clusters differently colored. Mean young of the year brown trout density ($0+/100\text{m}^2$) for each cluster: Cluster 1 (green): 84.4, cluster 2 (red): 38.8, cluster 3 (yellow): 8.4, cluster 4 (black): 71.7 and cluster 5 (blue): 25.1.

Over all there were significant differences in the mean values of 0+ brown trout densities and the mean values of the environmental factors between the five clusters (ANOVA, $df = 4$, $p < 0.05$). For the two environmental factors “Annual air temperature” and “Altitude” there were significant differences in mean values between all clusters. For the two environmental factors “Longest period above 0°C ” and “Mean water depth” there were significant differences in mean values between clusters in 9 out of 10 pairwise comparisons. For “Young of the year” densities and the environmental factors “Maximum slope” and “Mean stream width” there were significant differences in mean values between clusters in 7 out of 10 pairwise comparisons. For the environment factor “Water flow” there was only significant differences between clusters in 4 out of 10 pairwise comparisons (Table 3). The result of the cluster analysis gave a mean stream width for cluster 1 and cluster 4 with the highest mean 0+ brown trout densities at 10.8 and 3.66m. The analysis showed a statistically significant difference in stream width between the two clusters but no significant difference in mean 0+ brown trout density. Cluster 3 had highest mean stream width (143.52m) and the lowest mean 0+ brown trout density. For this cluster the mean

stream width was statistically significant different from the rest of the clusters and the mean 0+ density was significantly different from all but one other cluster. The cluster analysis showed a statistically significant difference in mean water depth between all but two of the clusters, cluster 1 and 2. Cluster 1 with the highest mean 0+ density had the lowest mean water depth (0.24m) and cluster 3 with the lowest mean 0+ density had the highest mean water depth (0.33m).

Cluster 1 had the highest mean 0+ brown trout density value which was significantly different from all clusters except for cluster 4 which had the second highest mean 0+ density value. Cluster 1 had the highest annual air temperature mean value, the longest period above 0 °C and the lowest altitude mean value which for all three factors were significantly different from the mean values of the rest of the clusters. Cluster 2 and cluster 4 had approximately the same geographical distribution but they had significant different mean values of 0+ brown trout density, stream slope, annual air temperature, longest period above 0 °C, altitude, stream width and water depth. The only environmental factor that was not significant different between cluster 2 and cluster 4 was the mean water flow values. Cluster 3 had the lowest mean 0+ brown trout density which as well as the environmental factors were significantly different from the mean values of the clusters 1, 2 and 4. The mean values of the environmental factors for cluster 3 were either highest or lowest, except for the mean altitude value, when compared to the mean values of the environmental factors of the rest of the clusters. Cluster 3 had the lowest stream slope mean value, the highest water flow mean value, the lowest annual air temperature mean value, the shortest period above 0 °C mean value, the next highest altitude mean value, the highest stream width mean value and the highest water depth mean value. Cluster 3 mainly correspond to larger rivers with a mean water flow and stream width at approximately 290% respectively 145% higher than the average water flow and stream width mean values for the other clusters. The mean 0+ brown trout density values for the clusters seem to be negatively affected by high mean water flow and stream width values but this might also be an effect of difference in catchability of 0+ brown trout in small streams compared to large rivers. Cluster 3 and cluster 5 overlapped geographically in the extent of cluster 3. They did not have a significant difference in 0+ densities or longest period above 0 °C but they had significant differences in mean values for stream slope, water flow, annual air temperature, altitude, stream width, and water depth. Water flow and stream width were the environment factors with the largest difference in mean values between the clusters with highest and lowest mean.

Table 3. Mean values and lower and upper confidence limits (in brackets) for young of the year densities and environmental factors. Coefficients of variance for the mean young of the year density values are shown in square brackets. Last column shows for how many out of the 10 pairwise comparisons there were a significant difference between clusters. Superscript letters indicate which clusters that had significant differences in mean values. Same letter after mean values means no significant difference in mean values.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Significance
Young of the year (0+/100 m²)	84.4 ^A (75.1 / 93.7) [1.5]	38.8 ^B (34.4 / 43.3) [1.8]	8.4 ^C (5.8 / 11.1) [3.1]	71.7 ^A (62.9 / 80.5) [2.3]	25.1 ^{BC} (20.8 / 29.4) [2.9]	7 / 10
Stream slope (%)	2.3 ^{AB} (2.2 / 2.4)	2.5 ^{AC} (2.4 / 2.6)	1.0 (0.8 / 1.3)	8.2 (7.9 / 8.6)	2.3 ^{BC} (2.2 / 2.5)	7 / 10
Water flow (m³/s)	4.8 ^{ABC} (4.0 / 5.6)	4.9 ^{ADE} (4.1 / 5.7)	126.2 (114.4 / 138.0)	2.3 ^{BDF} (1.4 / 3.2)	5.1 ^{CEF} (3.7 / 6.5)	4 / 10
Annual air temperature (°C)	7.7 (7.6 / 7.8)	4.5 (4.5 / 4.6)	0.7 (0.4 / 1.0)	5.0 (4.8 / 5.2)	1.7 (1.6 / 1.8)	10 / 10
Longest period above 0 °C (days)	224.4 (223.0 / 225.8)	190.4 (189.8 / 191.1)	163.7 ^A (161.6 / 165.9)	197.2 (195.3 / 199.2)	166.7 ^A (165.3 / 168.1)	9 / 10
Altitude (m.a.s.l.)	61.8 (57.8 / 65.7)	146.7 (141.1 / 152.2)	237.7 (216.1 / 259.4)	168.3 (157.8 / 178.8)	401.9 (386.6 / 417.2)	10 / 10
Mean stream width (m)	10.8 ^{AB} (9.6 / 12.0)	11.3 ^{AC} (10.3 / 12.3)	143.5 (125.4 / 161.7)	3.66 (3.5 / 3.9)	14.0 ^{BC} (11.6 / 16.3)	7 / 10
Mean water depth (m)	0.24 ^A (0.24 / 0.25)	0.23 ^A (0.23 / 0.24)	0.33 (0.32 / 0.35)	0.20 (0.19 / 0.20)	0.30 (0.29 / 0.32)	9 / 10

The environmental factors mean annual air temperature and altitude were significantly different between all clusters and the factor longest period above 0 °C was significantly different in 9 out of 10 pairwise comparisons between the clusters indicating that climatic conditions are important for the brown trout. Another indication of the importance of annual air temperature and altitude is that these environmental factors together with the mean 0+ brown trout density were significantly different between cluster 2 and cluster 4 which had approximately the same geographical distribution. There seem to be a connection between higher 0+ brown trout densities and higher annual air temperature, longer period above 0 °C and lower altitude (Figure 7A-C). These three environmental factors are also interconnected, as a lower altitude might give higher annual air temperature and a higher annual air temperature might give a longer period above 0 °C.

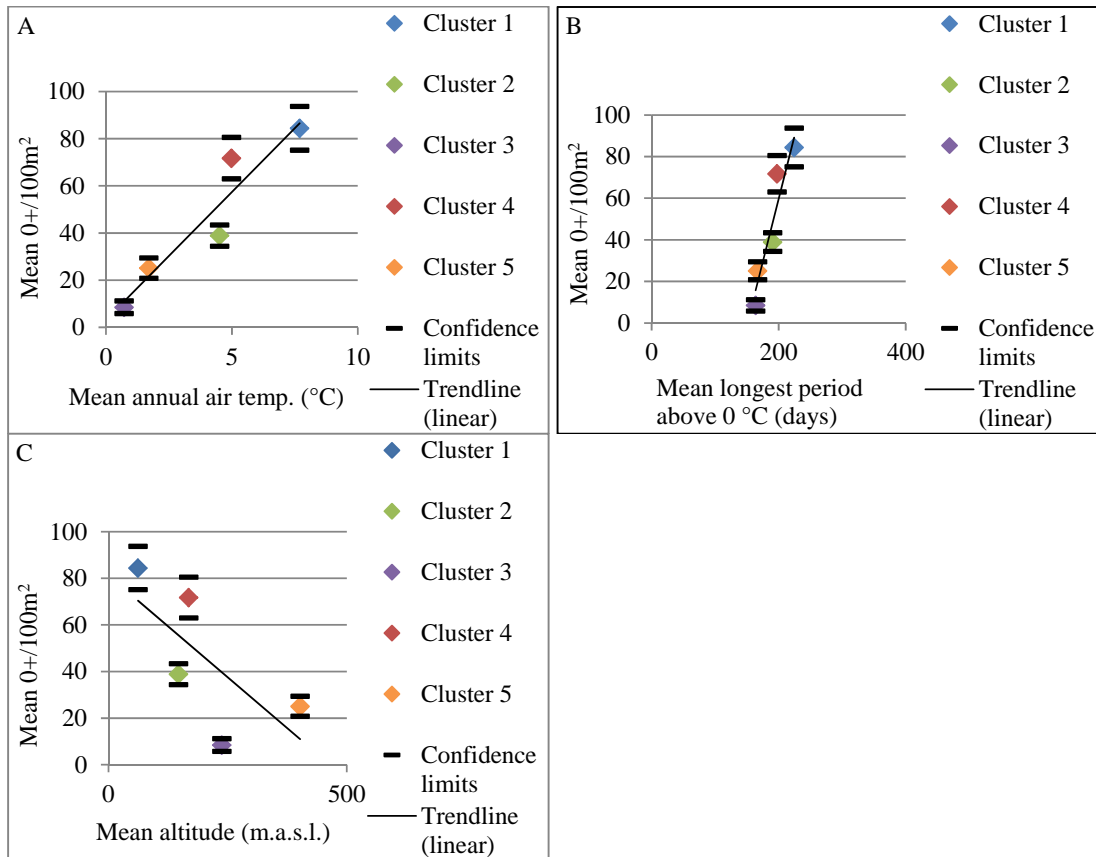


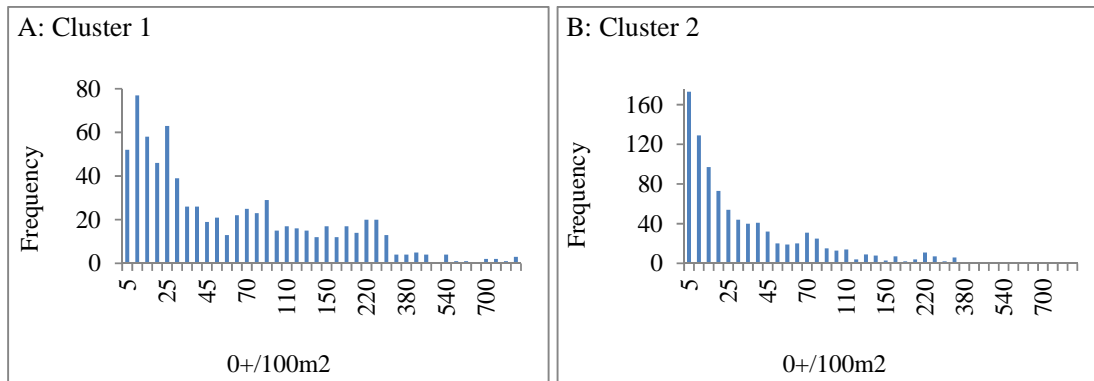
Figure 7. Correlation between the five clusters mean 0+ brown trout density and the mean values of the environmental factors A: Annual air temperature (°C), B: Longest period above 0 °C (days) and C: Altitude (m.a.s.l.).

The main difference between the distributions of 0+ brown trout densities of the different clusters was in number of FO with high densities. The 0+ brown trout distribution followed a pattern of a large number of FO with low densities and a smaller number of FO with high densities for all of the clusters. The 0+ brown trout distribution of cluster 1 and cluster 4 which were the clusters with the highest mean 0+ brown trout values differed from the rest of the clusters with a larger number of FO with high densities. Cluster 3 and cluster 5 had lower 0+ brown trout density values, 0.1/100m² and 0.2/100m², compared to the lowest 0+ brown trout values for cluster 1, cluster 2 and cluster 4 which were 0.4/100m², 0.4/100m² and 0.7/100m² respectively. Cluster 1 had 759 FO and 0+ densities between 0.4 –

1850/100m² with a mean 0+ brown trout density of 84.4/100m² (LCL = 75.1 and UCL = 93.7, CV = 1.5). Cluster 2 had 906 FO and 0+ densities between 0.4 – 1378/100m² with a mean 0+ brown trout density of 38.8/100m² (LCL = 34.4 and UCL = 43.3, CV = 1.8). Cluster 3 had 102 FO and 0+ densities between 0.1 – 76.3/100m² with a mean 0+ brown trout density of 8.4/100m² (LCL = 5.8 and UCL = 11.1, CV = 3.1). Cluster 4 had 396 FO and 0+ densities between 0.7 – 637/100m² with a mean 0+ brown trout density of 71.7/100m² (LCL = 62.9 and UCL = 80.5, CV = 2.3). Cluster 5 had 282 FO and 0+ densities between 0.2 – 213/100m² with a mean 0+ brown trout density of 25.1/100m² (LCL = 20.8 and UCL = 29.4, CV = 2.9) (Table 4 and Figure 8A-G).

Table 4. Distribution of brown trout density (0+/100m²) for each of the five clusters.

	Number of fishing occasions	Brown trout density (0+/100m ²)	Relative frequency (%)
Cluster 1 (759 FO)	427	0.4 - 50	56
	300	> 50 - 300	40
	32	> 300 - 1850	4
Cluster 2 (906 FO)	703	0.4 - 50	78
	123	> 50 - 100	13
	80	> 100 - 1378	9
Cluster 3 (102 FO)	84	0.1 - 10	82
	18	> 10 - 76.3	18
Cluster 4 (396 FO)	234	0.7 - 50	59
	107	> 50 - 150	27
	54	> 150 - 637	14
Cluster 5 (282 FO)	142	0.2 - 10	50
	95	> 10 - 50	34
	45	> 50 - 213	16



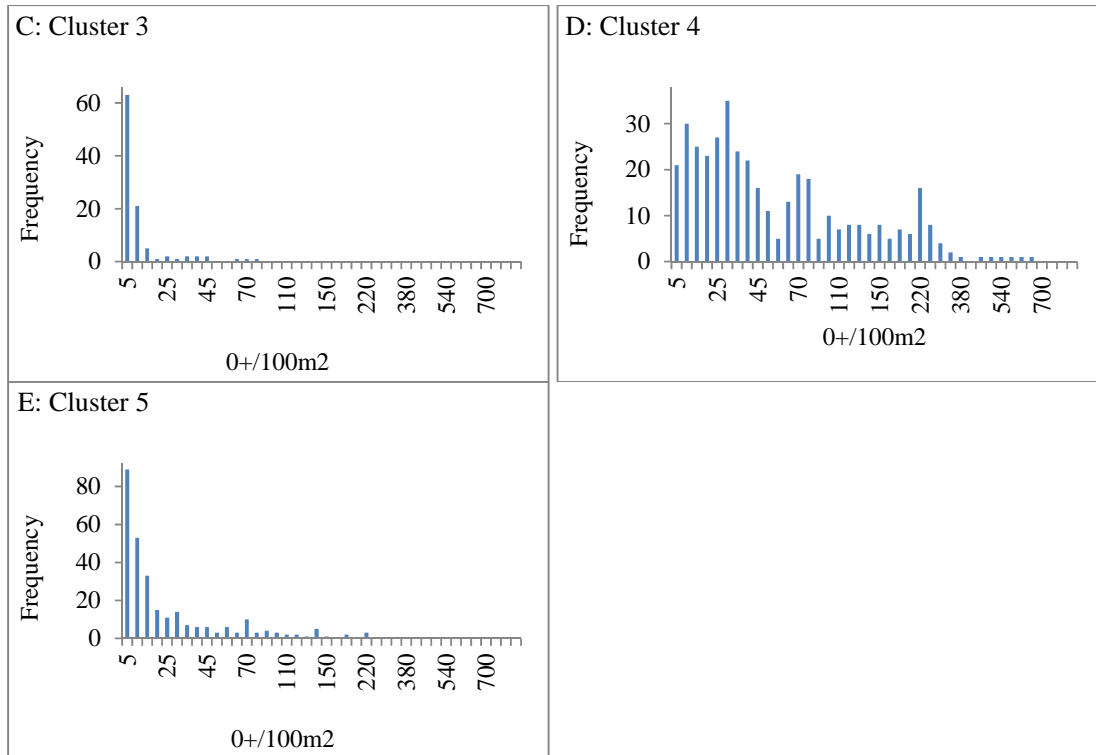


Figure 8. Distribution of 0+ brown trout densities for A: Cluster 1, B: Cluster 2, C: Cluster 3, D: Cluster 4 and E: Cluster 5.

3.3 Relative uncertainty in 0+ estimates

The uncertainty of the clusters' mean 0+ brown trout densities were compared to the uncertainty of estimated 0+ brown trout densities from traditional electrofishing data to see how the levels of uncertainty would spread for estimated 0+ brown trout densities based on the summed up 0+ brown trout production of a stream compared to estimated 0+ brown trout densities based on electrofishing of a whole stream. All the calculated PRP values were within an acceptable level of uncertainty, between 6.82 - 31.88%, when compared to the calculated PRP values of estimated 0+ brown trout densities from traditional electrofishing with 3 removals which were between 60 - 120%. The PRP values were lower for clusters with larger number of FO and the PRP value of the mean density of 0+ brown trout for all clusters together (2445 FO) was the lowest at 6.82%. This was below the PRP value of estimated 0+ brown trout densities from traditional electrofishing based on 5 removals which was approximately 15% at the same 0+ density. The PRP value of the mean density of 0+ brown trout for cluster 3 was the highest at 31.88% which was at the same level as the RPR value of estimated 0+ brown trout densities from traditional electrofishing based on 4 removals at the same 0+ density. The PRP values for the clusters 1, 2, 4 and 5 were at between 11 - 17.20% at the same level as the PRP values of estimated 0+ brown trout densities from traditional electrofishing based on 5 removals at the same densities. The estimates of 0+ brown trout densities and PRP values from traditional electrofishing data were made based on approximately 10 000 electrofishing occasions from whole of Sweden with cumulative catches ($p_1 = 0.48$, $p_2 = 0.70$ and $p_3 = 0.90$) which yields an average catchability of 0.38 (Bergquist et al., 2014). The levels of uncertainty were higher at low 0+ brown trout densities and considerable lower for traditional electrofishing with 5 removals than with 3 removals. Traditional electrofishing with 3 removals had an uncertainty of more than 100% at a 0+ brown trout density of 25/100m²

whereas for traditional electrofishing with 5 removals the uncertainty was just below 20% for the same 0+ brown trout density. At a 0+ brown trout density of 325/100m² the uncertainty for traditional electrofishing with 3 removals was 30% whereas the uncertainty for traditional electrofishing with 5 removals was only 6% at the same 0+ brown trout density. When comparing the mean 0+ brown trout densities of the cluster analysis with estimated 0+ densities based on traditional electrofishing data with 3, 4 and 5 removals respectively, the cluster analysis uncertainty values (e.g. confidence limits) for all clusters together and clusters 1, 2, 4 and 5 matched the estimated uncertainties based on electrofishing with 5 removals (Figure 9).

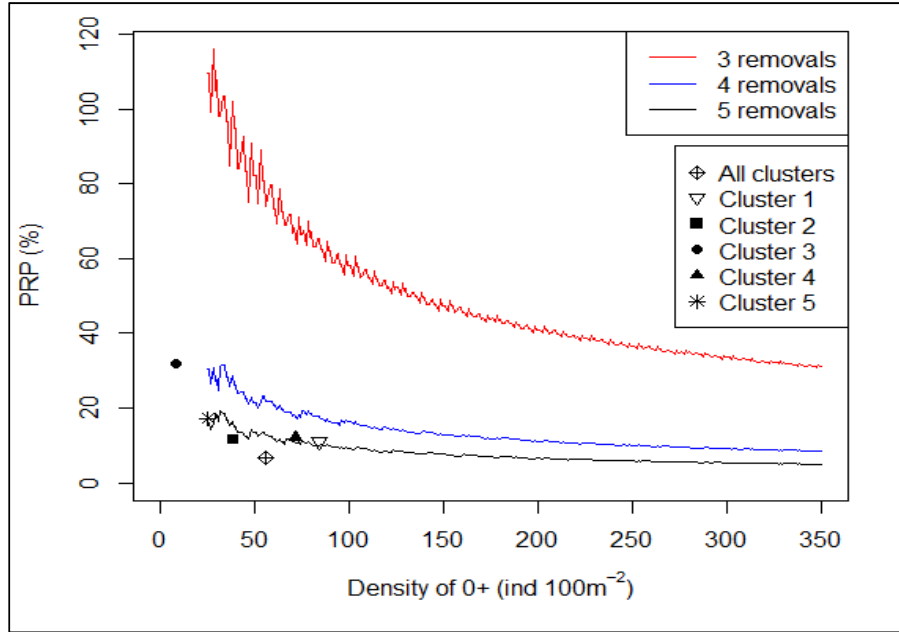


Figure 9. Uncertainty in estimated densities of 0+ brown trout based on traditional electrofishing compared to the mean values of 0+ brown trout from the cluster analysis. Line estimates based on traditional electrofishing data with 3 (red line), 4 (blue line) and 5 (black line) removals. Points are the mean values of 0+ for all clusters together and for each cluster apart plotted against their PRP (percentage relative precision) values. The PRP values are a percentage of the mean densities and tell the relative uncertainty of the means.

The comparisons of uncertainties between mean densities in the clusters and single electrofishing results is not directly comparable due to the differences in number of samples. Although it still gives a hint on the problems in scaling up the density estimate results to cover a whole river from a few electrofishing sites in a single river. When summing up densities for an entire drainage area the individual observations in the relevant clusters needs to be used and therefore the presented PRP-values will not directly scale up to represent the uncertainty of the total population size. A more sample independent measure of the comparisons between the clusters and results from single estimates from electrofishing at the same mean densities shows that the coefficients of variation were about 4 - 8 times higher in the clusters than in the electrofishing. The lowest variation was found for cluster 1 and the highest for cluster 3. The variation is due to between site variation, indication the need for many sites to cover the spatial variation in a river if done purely by means of electrofishing.

4. Discussion

The mean 0+ brown trout density values from the cluster analysis were found to be useful to predict the maximum production capacity of 0+ brown trout. It provides uncertainties in the cluster analysis that are lower than what can be obtained at a few sites in traditional electrofishing with 3 removals, which is standard when electrofishing is used for estimation of fish population sizes in Sweden today. As the uncertainty for the 0+ brown trout density estimates of the cluster analysis includes effects of the spatial heterogeneity it should be possible to get reliable 0+ brown trout density estimates of a whole stream with the use of environmental data. Using this method to estimate 0+ brown trout densities would mean connecting environmental data of a stream subsection in the same size as an electrofishing site to the cluster with the most closely resembling environmental factors, and doing so for all subsections of the entire stream.

The connections found during the work with this thesis between 0+ brown trout densities and environmental factors are similar to what have been found in other studies. In their report on habitat requirements of Baltic sea trout parr ICES (2011c) concluded that optimum habitat conditions are found at sites with water depth < 0.3m, stream width < 6m and 0.5 - 3% stream slope. As habitat preferences for brown trout year classes overlap the preferences for brown trout parr are transferable onto 0+ brown trout (Armstrong et al., 2003). The clusters mean water depth were < 0.3m for 3 of 5 clusters, the cluster with the highest mean 0+ density had the lowest mean water depth and the cluster with the lowest mean 0+ density had the highest water depth. The clusters mean stream width were all except for one higher than < 6m and ranged between 3.6 - 13.95m with one outlier at 143.52m. But as with the mean water depth the clusters with the lowest stream width had the highest mean 0+ density and the cluster with the highest stream width had the lowest mean 0+ density, consistent with earlier studies suggesting that stream size is negatively correlated to 0+ brown trout density (Bohlin et al., 2001; Eklöv et al., 1999). The clusters mean stream slope values were all but one in the preferred range suggested by ICES (2011c), between 1.73 - 2.47%. The cluster with lowest mean 0+ density also had the lowest mean stream slope. The one cluster outside the range had much higher mean stream slope (8.23%) than the rest of the clusters but it had the second highest mean 0+ density which seem to be non consistent with earlier studies which suggest that higher stream slope negatively affects brown trout abundance and density at a stream reach scale (Isaak & Hubert, 2000; Chisholm & Hubert, 1986).

There were three environmental factors that had a somewhat linear relationship with 0+ density: annual air temperature, longest period above 0 °C and altitude. For annual air temperature and altitude there were a statistically significant difference in mean values between all of the clusters and for longest period above 0 °C between all but two of the clusters. Consistent with previous studies (Bohlin et al., 2001; Eaton et al., 1995; Rahel et al., 1996; Rahel & Nibbelink, 1999) the clusters with highest mean annual air temperature and longest mean period above 0 °C had the highest mean 0+ densities whereas the cluster with the lowest mean altitudes had the highest mean 0+ densities. According to this altitude and local climate are important to and possible constraining the production in brown trout populations. The water flow values used in the analysis were taken from SMHI data of water flow at the outlet of the drainage area that each of the electrofishing sites were located in. This makes for a rather uncertain estimation of water flow for each electrofishing site. Although in the cluster analysis the cluster with lowest mean 0+ density had an extremely high mean water flow (126.19m³/s) indicating that as according to Crisp

(1996) and Bret et al. (2016) water flow is an important environmental factor and that high water flow have a negative impact on 0+ brown trout production and survival. The mean water flow values of the other clusters were only statistically significant different from this cluster's extremely high value but there were no significant differences between the mean values of the other clusters which ranged between 2.33 - 5.08m³/s.

The method tested in this study, with environmental factors and cluster analysis, could give a more reliable estimate of the maximum 0+ brown trout density in a stream and also be more time and cost efficient than electrofishing since the variation within and between the clusters include the effects of variation between sites. There would be a need for many electrofishing sites in a river to have the same accuracy and precision in an estimate of the total maximum production of young of the year brown trout. Another advantage of using environmental factors to estimate maximum 0+ brown trout densities is that this method does not require long time series in the same way that traditional electrofishing do. With traditional electrofishing data from several years are required to avoid getting density underestimations which can be a risk if estimation are based on lower or much lower fish densities than the possible density for the stream and electrofishing site. The environmental factor and cluster analysis method could therefore be more reliable and efficient to use for 0+ brown trout density estimation when small or low density populations are monitored.

In conclusion, estimation of the maximum 0+ brown trout productivity for a whole stream is possible with the use of data on environmental factors and the cluster analysis information, and the approach makes it possible to handle the uncertainties as well. The targeted stream would have to be divided into subsections in the same sizes as an electrofishing site for it to be connected to the right cluster as the data used in the cluster analysis are based on electrofishing site data. It would require a way to connect the stream subsections environmental factors to the clusters of which they are most environmental alike. The estimated 0+ brown trout density for a whole stream would then be estimated based on the 0+ brown trout density of the stream subsections. The method to calculate the maximum production of a river would be to use the environmental information from the entire river and assign the most appropriate cluster number to each subsection of the river. Thereafter a bootstrap can be used to randomly pick a single density from each of the subsections' cluster in each draw. Summing these densities will give one measure of the maximum production, and repeating the procedure several thousand times will give enough data to calculate mean and the desired measures of uncertainty.

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